Recommendations for a Department of Energy Nuclear Energy R&D Agenda

Appendix 5
Pros and Cons of Objectives and Options

1.0 INTRODUCTION AND SUMMARY

Nuclear power plays a significant role in the U.S. economy, and (barring unforeseen circumstances) will continue to play one at least until the end of the licensed lifetimes of the majority of the currently operating reactors. Major issues are facing the nation that may well result in a reemergence of nuclear power as a potential contributor to the nation’s environmentally sound energy security goals. Moreover, the need to confront major issues associated with nuclear power will endure far beyond the lifetime of the current generation of reactors.

With these realities in mind, the underlying issue is not whether to continue nuclear power or nuclear power research, rather it is to what extent is nuclear power and nuclear research necessary to ensure vital national interests?

Review of the issues, scenarios, and implications for policy and R&D clearly indicates three major themes, or challenges, for the U.S. common to any nuclear future, even one in which nuclear energy declines both worldwide and domestically:

- *Influence:* How does the U.S. best influence the rest of the world in critical nuclear issues such as nuclear safety, nonproliferation, and waste management?
- *Infrastructure:* How do we maintain sufficient expertise and infrastructure to deal with the enduring nuclear legacy, both domestically and internationally?
- *Future options:* Can the U.S. truly afford to preclude the use of nuclear energy in a future with unclear environmental and energy security issues?

These challenges are at the root of the U.S. government’s role in nuclear power and nuclear power research. In addition, government has responsibility for promoting the nation’s economic competitiveness. From an energy perspective, this means ensuring that the nation’s energy needs, considering all constraints and including nuclear, are met as productively and economically as possible.

Before assessing the pros and cons of the policy and R&D options discussed in previous sections of this study, it is useful to recall some of the benefits and risks associated with nuclear power. Some of the major benefits of nuclear power are:

- It is a significant, dependable, and independent U.S. domestic energy resource.
  - Nuclear power provides over 20% of the domestic electrical energy supply.
  - It is a domestically “independent” energy source, reliable in face of international tensions and market uncertainties.

- It is safe and environmentally sound.
  - Nuclear energy has no direct emissions of CO_2, acid rain, or other environmentally sensitive effluents.
  - It is a safe energy source, notwithstanding continuing concerns and issues.
- Maintains U.S. positions of technical leadership and influence in important international policy areas such as nonproliferation, safety, and waste management.

There are, of course, risks associated with nuclear power:

- There are proliferation implications and risks with nuclear power internationally.
- Spent fuel and waste management, even though technically resolvable, are significant socio-political issues.
- Because of the magnitude of the consequences of a nuclear accident (even more so, the magnitude of the uncertainties surrounding the consequences), nuclear safety remains a significant issue.
- The cost of nuclear power is currently unacceptably high relative to most alternatives.

Just as there are risks associated with nuclear power, there are risks associated with *not* exploiting nuclear power:

- Loss of international influence and technical leadership:
  - With no viable domestic nuclear energy program, U.S. ability to influence international nuclear policy decisions, including major international issues of nonproliferation, safety, and waste management, will deteriorate even further.
  - With no U.S. leadership in proliferation-resistant technologies and no viable U.S. reactor industry, developing countries must opt for indigenous reactor systems or choose other available systems, potentially resulting in even less proliferation resistance than current U.S. designs.
- Erosion of critical infrastructures — the infrastructure necessary to effectively deal with significant nuclear issues, including D&D, waste management, and nuclear facility safety will erode.
- Impairment of energy options and flexibility:
  - The U.S. will become more dependent on fossil fuels in the short term, and perhaps in the long term, further increasing both demand and prices.
  - Our ability to stabilize carbon and greenhouse gas emissions will be impaired.
  - Flexibility of our electrical energy supply sector will be decreased, potentially postponing trends away from fossil fuel dependence, such as electric transportation.

In a very real sense, the analysis of the pros and cons of the alternative objectives, policies, and R&D programs for nuclear power must be developed from the perspective of how best to exploit the benefits of nuclear power and minimize the risks as they relate to nationally important goals.

If the U.S. is going to seriously meet its international environmental commitments, support a growing economy, and ensure its own as well as others' energy security, it must find ways to enhance and support nuclear energy as a part of the U.S. energy portfolio. No other energy source available today offers the demonstrated benefits of nuclear energy. Continued reliance on nuclear power in the U.S. and the significant energy security and environmental benefits of nuclear power will only be realized if the undesirable risks associated with nuclear power are reduced. These risks can be reduced by well-focused research and development.

In light of major and continuing uncertainties in the world's energy outlook and markets, clear needs for facilities and expertise to deal with existing and future security, safety, and environmental issues and continuing international tensions in much of the world, the U.S. simply cannot afford to allow its nuclear influence, infrastructures, or options to erode further.

Even if the current generation of domestic nuclear power is allowed to decline as a national resource, the U.S. is faced with the task of mitigating a clear set of unacceptable risks and addressing the related major challenges. These challenges will also require specific research and development efforts to reduce these unacceptable risks.

2.0 RELATIVE SIGNIFICANCE OF THE ISSUES IMPACTING NUCLEAR POWER

Rigorous implementation of decision theory requires assigning metrics to the various objectives (issues) and options. Rather than attempting to assign a quantitative ranking to the various issues impacting nuclear power, nuclear R&D, and the government's role, we will briefly discuss, in a nonrigorous relative way, the significance of these issues and the perspectives for their resolution.

Internationally there are three issues impacting nuclear power: two from the U.S. perspective and one from the perspective of foreign countries.

Proliferation is the dominant international issue from the U.S. perspective. "Business-as-usual" will likely only increase sensitivity to this issue. Major efforts in new technologies (fuels, reactor systems, spent fuel management, and international safeguards and safeguards technologies) are needed to address this issue.

Safety is a significant issue, both from the U.S. and foreign perspective. However, from the U.S. perspective (and notwithstanding legitimate altruistic motives) it is primarily an issue due to the potential impact of foreign reactor accidents on the U.S. program and economy. Resolution of the safety issue internationally requires two major elements. One is real technological change. The other is one of public perception.

Energy security is the major nuclear issue for most countries having or embarking on nuclear programs today. Although significant, energy security is not the major domestic issue in the U.S. today.

Domestic issues focus on the environment, economics and safety of nuclear power.

Safety of nuclear power has been the major domestic issue for the past two decades. As in the international safety issue, both technological change and modification of public perception are needed, but changes in safety philosophy and regulation are also needed to resolve this issue.

Environmental issues associated with, or avoided by, nuclear power are becoming increasingly important.

Carbon emissions and its avoidance by the use of nuclear power is the issue most rapidly growing in importance today.

Waste management and spent fuel disposition are, today, on par with the safety issue for nuclear power. Since most technical difficulties associated with this issue appear solvable, the issue is today primarily a social and political one, but resolution is difficult.

Infrastructure issues, particularly ensuring sufficient infrastructure and expertise to deal with the nuclear legacy independent of alternative nuclear futures, is a very important but often (and publicly) overlooked issue.

3.0 IMPLICATIONS OF ALTERNATE FUTURES

The U.S. can influence the future of domestic and international nuclear power by its definition and implementation of nuclear power policies, but it cannot control the nuclear future. Appropriate roles of government are to respond to current realities, to prepare the country to respond to reasonably expected futures, and to guard against unexpected futures. In Section 5, three scenarios for U.S. domestic and two for international nuclear energy futures were identified and are paraphrased below:

Domestic scenarios:

- *Gradual abandonment* of the nuclear power option in the U.S..
- *Continued reliance* on current nuclear generation technologies.
- *Reemergence* of nuclear power as the preferred option for new generating capacity.

International scenarios:

- *Decline* of worldwide nuclear power.
- *Growth* of nuclear power internationally.

Of the six possible combinations of these scenarios, Section 5 discussed the three domestic scenarios assuming international growth and briefly outlined the implications of a decline of worldwide nuclear power.

Currently, the domestic situation in the U.S. is one of gradual abandonment. No new reactors have been ordered for decades, a number of plants under construction have been abandoned, and existing plants are beginning to be shut down prematurely. Internationally, the rest of the world is generally seeing a growth of nuclear power.

The following table outlines the expected severity of the major challenges for government policy and R&D under the scenarios discussed above.

Relative severity of the major nuclear challenges under various scenarios

Scenario	Challenge		
	Influence	**Infrastructure**	**Future Options**
International Decline of Nuclear Power			
Domestic abandonment	Difficult	Very difficult	Very difficult
Continued reliance	Positive	Positive	Positive
Reemergence	Positive	Positive	Positive
International Growth of Nuclear Power			
Domestic abandonment	Very difficult	Very difficult	Very difficult
Continued reliance	Minor	Minor	Positive
Reemergence	Positive	Positive	Positive

The following sections will look at the implications of these scenarios (both domestic and international) with respect to the major challenges described above.

3.1 Implications on U.S. Nuclear Influence

One of the major challenges to the U.S. in any nuclear future is maintaining the nonproliferation and nuclear safety regimes, especially in the face of declining nuclear programs. This challenge is particularly difficult in future scenarios where the U.S. share of the nuclear market continues to decrease.

In the past, some foreign countries pursued nuclear power partially as an affirmation of national technical achievement and pride. This goal, while still part of some country's nuclear agenda, has substantially subsided in the face of the technical and economic difficulties continuing to plague nuclear power worldwide. Today, one of the prime reasons for embracing nuclear power is the lack of affordable energy alternatives in the face of increasing demand.

As past events have shown, the U.S. has little ability to effectively alter worldwide energy issues and markets. Without reasonable optional energy sources, many countries will likely opt for whatever nuclear power systems are commercially available in the future. The U.S. international goals of nonproliferation, safeguards, and nuclear safety can be furthered only if affordable energy systems conducive to those goals are available, and that can be assured only if the U.S. provides and supports those alternatives.

Policies under which the U.S. removes itself from participation in domestic and/or international nuclear power development cannot provide those alternatives.

A decline and abandonment of nuclear energy in the U.S. would significantly reduce U.S. influence on nuclear energy issues worldwide without overt efforts to provide support essential to the international safeguards, nonproliferation, and safety regimes. The U.S. has sufficient coal and natural gas reserves to enable the U.S. to abandon nuclear power as "an example" for others. Nations lacking the energy reserves of the U.S. recognize this as a luxury they cannot afford. Without acceptable alternatives (whether new proliferation-resistant reactors and fuel cycles, or economically and environmentally acceptable alternatives), many such nations will rely on non-U.S. nuclear suppliers. Lack of a U.S. nuclear program would make some arms reduction efforts, notably those aimed at reducing former Soviet HEU and plutonium stockpiles, very difficult.

Even under a worldwide decline in nuclear power, disposition of spent fuel and separated plutonium, waste management, safety of aging plants, and decommissioning present significant issues of vital interest to the U.S. Influence in many of the these areas will require both technical leadership as well as political leadership. Current U.S. inability to resolve waste, spent fuel, and excess weapons materials disposition is seriously undermining our ability to influence similar issues worldwide.

Either continued reliance on U.S. nuclear power generation or reemergence of the nuclear option in the U.S. presents similar challenges to U.S. influence internationally. While the U.S. position and influence would increase internationally relative to those under an abandonment of the nuclear power in the U.S., such a scenario demands effective improvements in safety, waste management, and proliferation resistance beyond those of current systems and operations, both for the real benefits gained and for the international examples provided.

3.2 Implications on Nuclear Infrastructures

Under any of the domestic and international scenarios for nuclear energy, there is and will be a continuing need to maintain a robust nuclear infrastructure to manage the nuclear legacy. The only questions raised by the various scenarios are the extent of that infrastructure and the difficulty in maintaining the infrastructure.

Scenarios pessimistic to the future of nuclear energy present the major challenge to preserving and maintaining infrastructure. Without a robust nuclear economy and continuing nuclear R&D, it is difficult to entice and train needed specialists and industrial capabilities and to maintain the necessary technical expertise. Even today, with the world's largest installed nuclear capability, the uncertain future of the domestic U.S. nuclear industry has resulted in ever-declining enrollment of nuclear science students at U.S. universities.

Pessimistic futures for nuclear power do not significantly change the kinds of infrastructures required, they only change the size of the individual components. For example, were there to be no new reactors operated, we would likely continue reactor operations through the end of most reactors' lifetimes and would need safety systems, plant safeguards, and operations for another 40 years or so. We would continue to require spent fuel management for at least another 50 years and would require continued operations of repositories and other waste management facilities for some time later yet.

Internationally, the potential for a worldwide decline in nuclear power appears less likely than in the U.S., but some of the challenges in that event are substantial. Commercial reprocessing and separation of plutonium has outstripped the rate of utilization of plutonium as fuel in reactors. Current projections suggest over 200 metric tonnes of plutonium will have been commercially separated by the year 2000. A premature decline in worldwide nuclear power could result in much or nearly all of these inventories having no clear disposition path.

Relying on the current level of nuclear power generation and potential expansion of the role of nuclear power, either domestically or worldwide, would both serve to maintain the current nuclear infrastructure. However, such scenarios would require improvements in the ability of the nuclear programs to meet increasingly stringent demands on nuclear safety, waste management, safeguards, and nonproliferation.

Reliance or growth of nuclear power would be viewed, particularly by the developing countries, as reinforcing the desirability of nuclear power. This would place additional incentives for the development of proliferation-resistant reactor systems and fuel cycles, as well as on developments aimed at improving the current LWR fuel cycle and proliferation resistance.

3.3 Future Use of Nuclear Power

The current domestic decline of nuclear power is due primarily to economics and increasing public concern regarding nuclear safety and waste management. The relative economics of nuclear power depend strongly on the economics of alternative choices, currently mostly coal. Increasing concern over the environmental impacts of fossil fuel combustion is likely to increase the cost of these fuels, and the potential for alternative sources appears limited. It is not unlikely that future use of nuclear power may be considered both economically and environmentally.

Maintaining the option for nuclear power, even in the face of domestic decline and the (small) possibility for international decline is current U.S. policy, and one that helps protect vital U.S. environmental, economic, and energy security issues. Continued maintenance of nuclear power as a viable option for future use relies on meeting several significant challenges:

- Solutions for or significant progress in the management and disposition of nuclear waste and spent fuel.
- Improvements in safety, operations, and management of nuclear systems.
- Development of alternative approaches to proliferation-resistant systems and fuel cycles.
- Development of improved nonproliferation and safeguards technologies and regimes.

4.0 PROS AND CONS OF ALTERNATIVES AND REQUIRED RESPONSES

Both Tasks 4 and 5 concluded that three general alternatives appear possible for the future of nuclear energy and nuclear energy policy in the U.S. The three alternatives are, in effect, policy descriptions:

- *Gradual abandonment*. The U.S. Government essentially divorces itself from the nuclear option, and concentrates on safety, environmental cleanup, and decommissioning domestically and aggressively pursues its international nonproliferation agenda.
- *Continued reliance*. The U.S. Government continues to support the current role of domestic nuclear power primarily to preserve the domestic nuclear option for future use and tolerates foreign nuclear developments under effective international safeguards.
- *Reemergence*. The U.S. Government endorses nuclear power and supports active development of new and improved reactor systems both domestically and internationally.

Task 4 identified four alternative paths for U.S. government involvement for both domestic and international nuclear energy. These alternatives range from essentially no government support for nuclear energy to a more aggressive, future-oriented role in nuclear R&D. These alternatives represent policy options, with the foreign and domestic options serving as dimensions in a 4-by-4 matrix. In the conclusions, Task 4 noted that three of the possible 16 combinations appeared the more reasonable subset for discussion. These three map well onto the three suggested above.

The three scenarios presented in Task 5 were predicated on the assumption that nuclear energy would continue to grow internationally, and discussed the alternative scenarios from the perspective of how each would impact the U.S. ability to participate and to influence the international nuclear decision process.

The following matrices summarize the implications of these three scenarios, assuming at least moderate growth in nuclear energy on an international scale. We also briefly identify the impact both slower and more aggressive international nuclear energy growth might have on these implications.

4.1 Implications of Gradual Abandonment

Implications of a gradual abandonment of nuclear power			
Objective	**Pros**	**Cons**	**Response**
National security			
Nuclear non-proliferation	Serve as an example for others Reduce ultimate accumulation of spent fuel and fissile materials	Loss of influence in international nuclear issues	Maintain leadership in technology through developing proliferation-resistant fuels, reactors and systems Increase international cooperation and dialogue
Energy security	None	Loss of significant domestic energy resource Increased reliance on fossil sources	Maintain underlying technology and infrastructure as a future option
National security	None	Erosion of underlying nuclear infrastructure	Maintain infrastructure
ES&H			
Safety	Reduced in risk of nuclear accident	Increased real overall risk to workers and public from alternative energy generating technologies Loss of technical expertise to maintain nuclear safety during phase-out, and cleanup of the legacy	Maintain nuclear option for the future Emphasize research in safety, decommissioning, and waste management
Environment	None	Increased greenhouse and sulfur emissions	Maintain nuclear option for the future
Waste management	Reduction in ultimate waste generated	Reduced incentive for effective, long-term waste management Loss of supporting technical expertise	Emphasize research in waste management
Economic competitiveness			
Economics	Possible-short term improvement in overall energy costs	Increased reliance on foreign expertise, goods and services Likely long-term increase in overall energy costs Loss of international markets	Maintain nuclear option for the future
Infrastructure	None	Significant loss of scientific and technical expertise and industrial capabilities	Maintain nuclear option for the future
Nuclear supply	None	Loss of capabilities	Maintain nuclear option for the future

4.2 Implications of Continued Reliance on Nuclear Power

Implications of continued reliance on nuclear power

Objective	Pros	Cons	Response
National security			
Nuclear nonproliferation	Maintains U.S. influence	Increased pressure on importance of safeguards Increased accumulation of spent fuel	Increased development of new safeguards technologies
Energy security	Maintains balanced energy supply mix	None	
National security	Maintains supporting infrastructures	None	
ES&H			
Safety	Real improvements in safety via both technical advances and regulatory reform	Requires real improvements in nuclear safety Requires overt efforts to improve public perception of nuclear safety	Increased R&D for nuclear safety
Environment	Reduces potential future increases in greenhouse gases and SO_2	Requires overt efforts to improve public perception of nuclear environmental impact	
Waste management	Improvements due to better integration of nuclear fuel cycle	Increased volumes of spent fuel accumulation	Improved spent fuel management and disposition methods and technologies
Economic Competitiveness			
Economics	Reduced overall long-term U.S. energy costs	Requires increased government funding of nuclear R&D	
Infrastructure	Maintains current domestic infrastructure		
Nuclear supply	Maintains current capabilities	None	

4.3 Implications of a Reemergence of Nuclear Power

Implications of a reemergence of nuclear power

Objective	Pros	Cons	Response
National security			
Nuclear non-proliferation	Potential reduction in proliferation risk via new technologies, processes and designs	Increased worldwide inventories and trade of fissile materials	Improved safeguards practices and technologies
	Enhancement of U.S. influence in international nuclear issues	Increased reliance on international safeguards	Improved spent fuel management and technologies
Energy security	Significant improvements in both domestic and international energy resources and security	None	
National security	Improved nuclear infrastructure supports related national security needs	None	
ES&H			
Safety	Reduced worker and public risk through improved safety and avoiding health and safety impacts of alternative technologies	Increased sensitivity to and importance of nuclear safety issues	Safety R&D
Environment	Significant reductions in emissions of environmentally sensitive effluents		
Waste management	Improvements in waste management technologies	Effective waste management continues as an important issue	Improved waste management technology and practices
Economic competitiveness			
Economics	Reduced energy costs by avoiding impact of escalating fossil energy costs		
	Improved U.S. position in international markets		
Infrastructure	Improved technical, scientific and industrial capabilities		
Nuclear supply	Improved nuclear supply capabilities		

4.4 Implications of a Worldwide Decline in Nuclear Power

Implications of a worldwide decline in nuclear power			
Objective	**Pros**	**Cons**	**Response**
National security			
Nuclear non-proliferation	Reduce ultimate accumulation of spent fuel and fissile materials	Orphaned separated plutonium spent fuel and waste management legacy Loss of nuclear infrastructure	Maintain leadership in technology through development of proliferation-resistant fuels, reactors and systems. Increase international cooperation and dialogue
Energy security	None	Loss of significant energy resources Increased reliance on fossil sources	Maintain underlying technology and infrastructure as a future option
National security	None	Erosion of underlying nuclear infrastructure	Maintain infrastructure
ES&H			
Safety	Reduction in risk of nuclear accident	Increased real overall risk to workers and public from alternative energy generating technologies Loss of technical expertise to maintain nuclear safety during phase-out, and cleanup of the legacy	Maintain nuclear option for the future Emphasize research in safety, decommissioning and waste management.
Environment	None	Increased greenhouse and sulfur emissions.	Maintain nuclear option for the future
Waste management	Reduction in ultimate waste generated	Reduced incentive for effective, long-term waste management Loss of supporting technical expertise	Emphasize research in waste management.
Economic competitiveness			
Economics	Possible short term improvement in overall energy costs	Likely long term increase in overall energy costs Loss of international markets	Maintain nuclear option for the future
Infrastructure	None	Significant loss of scientific and technical expertise and industrial capabilities	Maintain nuclear option for the future
Nuclear supply	None	Loss of capabilities	Maintain nuclear option for the future

5.0 SUMMARY R&D REQUIREMENTS

The previous chapter identified a number of R&D efforts required to respond to hypothesized future nuclear scenarios. These are summarized in the following 11 activities.

1. GLOBAL FUEL CYCLE SAFETY, SAFEGUARDS and SECURITY, and ACCOUNTABILITY RESEARCH—Research to enhance the safety, security, and accountability of existing and evolutionary fuel cycles will be critical in all foreseeable nuclear futures, including worldwide decline.

2. INTEGRATION OF THE NUCLEAR FUEL CYCLE—Research and analysis to develop and assess reactor *systems* for the future that integrate all aspects of the fuel cycle into systems that have the least proliferation potential, produce less waste and waste acceptable to a repository, have very high safety margins, and are highly cost-effective will be needed to support a continuing nuclear power generation capacity either domestic or foreign.

3. PROLIFERATION-RESISTANT REACTOR SYSTEMS—In all scenarios except worldwide decline, research must be conducted to develop concepts, strategies, and technologies to reduce or eliminate the potential for proliferation of nuclear materials and technology from nuclear energy systems. The objective is reactor systems, large and small, which if exported have little or no on-site refueling for the life of the reactor, and that have high safety margins, ease of operation, minimized waste production, and favorable economics.

4. UNDERSTANDING GLOBAL IMPLICATIONS AND APPROACHES TO NUCLEAR ENERGY—Develop and apply advanced energy/environmental/ economics models to examine probable scenarios for nuclear energy development and impacts, nationally and internationally, on future energy demand, the environment, and nuclear materials management and control issues.

5. ADVANCED FUELS FOR EXTENDED BURNUP AND WASTE MINIMIZATION—The development of advanced fuels is needed to support even the most marginal maintenance of current and future nuclear energy options. The very real challenges posed by spent fuel accumulation and waste disposal issues makes development of cost-effective solutions for waste management, including waste minimization through extended burnup and other technical features, a necessity.

6. WASTE MANAGEMENT—Independent of whatever scenarios develop, the need for dramatic improvements on current spent fuel and waste management technologies and practices cannot be overstated.

7. COMPUTATIONAL SCIENCE—Develop advanced, multidimensional computational tools and artificial intelligence technology using the national laboratories' state-of-the-art supercomputers to support development of advanced concepts, and assess the safety and security of current and proposed systems, while providing a user facility for academic research.

8. SAFETY, COST, AND QUALITY ASSURANCE—Appropriate cost, safety and regulatory considerations together form a major component of the potential for nuclear energy contributions. This initiative would analyze the connections among these features, and suggest regulatory and safety philosophy reforms that would enhance performance and safety while minimizing unnecessary schedule and cost impacts.

9. INSTITUTE FOR NUCLEAR ENERGY, SCIENCE, AND TECHNOLOGY—Provide opportunities for students and faculty from core universities to conduct collaborative research with national laboratory programs and mentors.

10. INTERNATIONAL DIALOGUE AND REGIONAL COOPERATION—In cooperation with the State Department and private U.S. industry, explore the interactions of technology with the development of regional frameworks to maximize U.S. involvement and interests, while serving as precedents for development of arrangements that allow for adequate energy production.

11. TECHNICAL AND INSTITUTIONAL INTERFACE—Many key challenges to nuclear activities lie at the interface of science and technology with institutional considerations. This initiative is intended to pursue scientifically meaningful methods for strengthening the ties between the technical and institutional features such as facility siting, transportation, and safety systems.

These 11 research areas contribute in various ways to the major challenges facing nuclear power. The following table summarizes the relationships between the research agendas and challenges.

Relationships between various research agendas and national nuclear challenges			
Research agenda	**Challenge**		
	Influence	**Infrastructure**	**Nuclear options**
Global fuel cycle	√	√	√
Fuel cycle integration	√	√	√
Proliferation-resistant reactors	√	√	√
Global implications	√		
Advanced fuels	√	√	√
Waste management	√	√	√
Computational sciences	√	√	√
Safety	√	√	√
Institute for nuclear S&T	√		
International dialogue	√	√	
Institutional interfaces	√		

Relationships between various research agendas and major issues								
	Issue							
Research agenda	**Non-prolif-eration**	**Energy security**	**National defense**	**Nuclear safety**	**Environ-mental impact**	**Waste manage-ment**	**Economics**	**Infra-structure**
Global fuel cycle	√	√		√	√	√	√	√
Fuel cycle integration	√	√		√	√	√	√	√
Proliferation-resistant reactors	√	√	√	√	√	√	√	√
Global implications	√	√	√	√	√	√	√	√
Advanced fuels	√	√	√	√	√	√	√	√
Waste management	√		√	√	√	√	√	√
Computational sciences	√		√	√	√	√	√	√
Safety		√		√			√	√
Institute for nuclear S&T	√			√	√	√		√
International dialogue	√	√		√	√	√		√
Institutional interfaces	√			√		√	√	√